SPECTROSCOPY OF MOUNT ETNA LAVA FLOWS AS A PROXY FOR AGE: A POTENTIAL ANALOGUE TO RECENT VOLCANISM ON VENUS. Gabriel L. Eggers[1], Justin Filiberto[2], Piero D'Incecco[3], Nicola Mari[4], Carmelo Monaco[5], Iván Lopéz[6], and Gaetano Di Achille[3]. [1]Lunar and Planetary Institute, USRA, Houston, TX 77058 (geggers@lpi.usra.edu), [2]Astromaterials Research and Exploration Science (ARES) Division, X13, NASA Johnson Space Center, Houston, TX, 77058, [3]National Institute for Astrophysics (INAF) - Astronomical Observatory of Abruzzo, Teramo, Italy, [4]Department of Earth and Environmental Sciences, University of Pavia, 27100 Pavia, Italy, [5]Dipartimento di Scienze Biologiche, Geologiche e Ambientale, Università di Catania, 95129 Catania, Italy, [6]Área de Geología, Universidad Rey Juan Carlos, 28933 Madrid, Spain.

Introduction: There is growing evidence of geologically recent volcanism at Venus [1–3], a question that may be resolved by forthcoming missions to our sister planet that will make spectroscopic measurements of the surface. The thick, relatively opaque atmosphere of Venus makes observation difficult, but a few key atmospheric windows in the near-infrared (NIR) around 1 μm make emission from the surface detectable [4]. At these wavelengths, the spectroscopic signature of rocks are due to its primary mineralogy and chemistry, as well as the presence of secondary weathering minerals [2, 5, 6]. If the degree of alteration can be tied to the spectroscopy of Venus analogue materials, then spectroscopy of venusian lava flows can potentially reveal their degree of weathering and thus their age, which in turn gives an estimate of the extent of recent volcanism [2, 7].

A potential Earth analogue to volcanoes on Venus is Mount Etna in Sicily, Italy [8]. This composite volcano is among the most active in the world and features mafic lava flows with definitive ages that exhibit varying degrees of alteration [9]. While Mount Etna is not a perfect analogue due to its different weathering environment, the natural age progression of altered basaltic rock can be a useful comparison. Here, we will investigate how weathering at Mount Etna affects spectroscopic measurements and if this can be used as a proxy for Venus.

While planned missions to Venus such as DAVINCI, VERITAS, and EnVision will measure NIR emissivity from the surface, Kirchhoff's Law states that $e = 1 - r$, where e is emissivity and r is reflectance, meaning that NIR emissivity can be estimated from reflectance measurements [10]. Given its relative ease, laboratory reflectance spectroscopy is a useful tool to efficiently test potential Venus analogue materials.

Samples & Methods: To test the spectroscopic response of weathering, samples were collected at Mount Etna from ten lava flows of both ʻaʻā and pāhoehoe types and ranging compositionally from basalt to basaltic andesite. Sampling locations are given in Figure 1. Most of the flows date to between 1610 and 2001, representing an age progression of ~ 400 years with associated natural weathering. Samples ET9 (from a flow dated to 2500 ± 30 BCE) and ET4 (from a flow of unknown age) are the two outliers to this temporal sequence.

We measured reflectance in the 0.5–2.5 μm range of the Mount Etna samples with a Spectral Evolution OreXpress spectrometer using the contact probe attachment ($\sim 30°$ phase angle) and a white Spectralon plate as reference. For all samples, spectra were taken on the both weathered surfaces and inferred fresher surfaces where the sample was more recently broken. To confirm the latter, a subset of samples (ET6, ET5, ET10, ET9, and ET4) representing a range of lava flow ages from young to very old (as well as the flow of unknown age) were cut open to take direct spectra of the unweathered interiors.

Figure 1: Mount Etna with lava flow sampling locations marked along with the year of eruption.

Results: Figure 2A shows a representative subset of spectra of the weathered exteriors for all ten Mount Etna samples. Several trends with age are observed. First, the overall reflectance of the sample spectra increases with age. At 1 μm, the youngest samples (< 50 years) exhibit reflectances of 5–10% while older samples ($\sim$ 200–400 years) have reflectances of 13–18%. This trend holds to the first order, but it is not universal: the oldest sample ET9 yields very low reflectances.

Second, the youngest samples exhibit a concavity of the curve near 1 μm indicative of their primary basaltic character. For older samples, this concavity gradually flattens and finally inverts as iron oxides—products of weathering of the primary rock—dominate the spectra.

Figure 2B shows spectra of the freshly cut interiors for a subset of the Mount Etna samples. Despite these samples ranging in age over hundreds of years, there

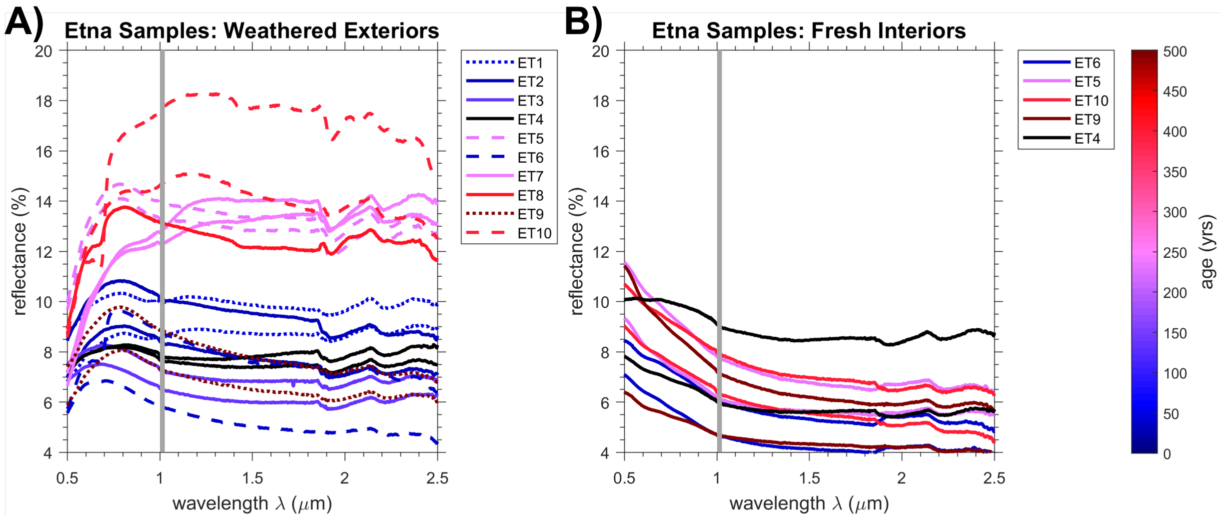

Figure 2: Full resolution spectra of (A) the weathered exteriors and (B) the fresh interiors of the Mount Etna samples. Spectra are color-coded by the age of the lava flows with blues being younger and reds being older (capped at 500 years). For the left panel, samples of similar age are further distinguished by the line style. The sample of unknown age is in black. The vertical grey line denotes ~ 1.02 μm, the relevant band at which the VIRTIS spectrometer onboard Venus Express observed [1].

is no progression with age. They all generally overlap and have low reflectances of 4–9% in the vicinity of 1 μm, comparable to (but still lower than) the spectra of the weathered exteriors of the youngest samples in Figure 2A. Moreover, there is no evidence of weathering products influencing the spectra of the older samples.

Discussion: The results demonstrate that spectroscopy can determine a general degree of alteration for basaltic rocks that in turn can serve as a proxy for the age of the sample, as has been argued based on laboratory experiments [2, 7]. On Venus, Idunn Mons in Imdr Regio has been argued as a potential location for recent volcanism due to summit lava flows that exhibit an anomalously high (though model-dependent) emissivity of 0.85–0.9 at 1.02 μm [1, 3], which is equivalent to a reflectance of 0.1–0.15 per Kirchhoff's Law. Assuming the trend observed in these Mount Etna samples holds, this corresponds to flows that are 10s to 100s of years old, which is both younger than the 0.25–2.5 Ma age estimated by [1] but older than couple of years estimate by [2]. It matches the decades to hundreds of years age estimated by [11], assuming a fully crystalline, pyroxene-dominated basalt. Regardless of the exact age estimated, it is consistent with Venus being volcanically active in the modern era.

However, the general trend observed with these Mount Etna samples should not be over-interpreted. While these spectroscopic measurements can reliably distinguish old from young samples, fixing an exact age is likely impossible with this technique. Even among samples of similar age, there can be sufficient variation such that the range of reflectances encroaches on that of samples of different ages, e.g., samples of flows that were a few decades old could be mistaken for an age in the low hundreds of years. This is in part due to the chemistry of the primary rock. For example, the reflectance of the weathered surface of Sample ET9, despite being from the oldest lava flow, matches the low reflectances of the much younger samples. However, even the reflectance of its fresh interior, while generally matching the other samples, is somewhat lower. The primary composition of a weathered lava flow will affect its spectra, complicating the interpretation of its age and highlighting the importance of understanding the spectroscopy of primary rock compositions under Venus conditions.

A final caveat is that Mount Etna is an imperfect analogue for Venus with a drastically different weathering environment, so the rate and nature of alteration will differ. However, alteration still has an observable spectroscopic effect on natural basaltic rock, which can be used to infer an approximate age. Future missions to Venus should prioritize spectroscopic investigations of Idunn Mons and other possibly active volcanoes.

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